

Detection of energy deposition down to the keV region using liquid xenon scintillation

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A possible method for WIMPs detection using liquid xenon scintillation is discussed [1]. Background from cosmic and radioactive gamma rays at energies down to the keV region can be easily rejected by requiring the presence of proportional scintillation. The results from a basic test are presented and a prototype detector design is proposed.

1. Introduction

A WIMP (weakly interactive massive particle) is expected to interact elastically with a nucleus in the target, and the energy is deposited in the medium by the recoiling nucleus. In the case of xenon, due to the high mass number of the nucleus, the subsequent ionization process in the liquid xenon will not be very efficient, even in the presence of a strong electric field, mainly because of a highly probable electron-ion recombination mechanism. As a consequence, scintillation light will be produced by de-excitation from the excited molecular states. The background to this process is due to cosmic rays, the residual radioactivity in

the detector elements and in the regions surrounding the detector itself, as well as neutrons. Cosmic rays and gamma rays from radioactive materials will be easily rejected, since they deposit energy in liquid xenon mainly due to minimum ionization. This process produces electron-ion pairs along their track. With appreciable electric field, one can control the electron-ion pair recombination so that both scintillation and free electrons will be produced. For very low energy (keV region) background, proportional scintillation [2] is useful since the number of electrons produced by ionization is very small.

The neutron background is the most dangerous source since it will produce primary scintillation similar

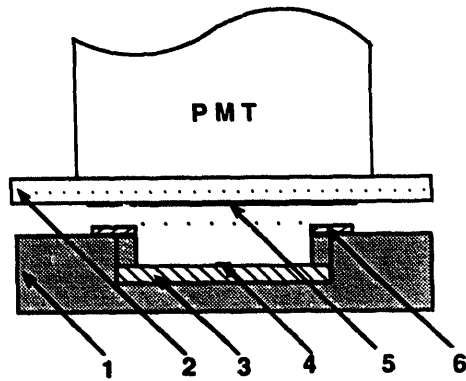


Fig. 1. Schematic drawing of the test chamber (1) HV insulator (Macor), (2) UV quartz window, (3) Cathode (stainless steel), (4) Source, (5) Grid (grounded), (6) Anode.

to that predicted for a WIMP interaction. In this case the most unambiguous signature would be a change in the event rate and in the spectrum of the energy deposition in one year time [3–5].

This report is organized as follows. Section 2 describes in detail the basic test setup. The results of the first test are presented in section 3, while section 4 illustrates the principles on which a future detector will be based and outlines some future prospects.

2. The test setup

The schematic drawing of the chamber used in the basic test is shown in fig. 1. The anode consists of 15 gold-plated tungsten wires with a very small diameter (3 to 4.5 μm) and a 2 mm pitch spacing on a stainless steel ring having a 32 mm inner diameter. The cathode is a stainless steel disc carrying on its center a small gamma (^{57}Co or ^{109}Cd) or a ^{241}Am alpha source. The distance between the anode and the cathode is 5 mm. A thin nickel coated mesh (having a transparency of about 90%) is fixed on a UV quartz window above the anode wires within a distance of 4 mm. In order to avoid a charge-up at the window the mesh is grounded. The photomultiplier (Hamamatsu R2050), whose photocathode has a quantum efficiency for 175 nm UV light of about 3.5%, is directly fixed on the window. The signal from the photomultiplier is amplified by a slow amplifier (Hamamatsu c1053-03, which rise time is about 100 ns).

A long cartridge of Oxisorb is used for the purification of the xenon gas. The purified gas is liquified in the chamber, which is plunged in a -100°C liquid Freon 11 bath controlled by a cooling device (HAAKE EK101). The chamber and the gas filling system are evacuated and baked out at 120 and 200°C respectively before liquefaction. The ultimate vacuum is less than

1×10^{-7} mbar and the outgassing rate after this procedure is 2×10^{-9} mbar l/s.

3. Results

The typical scintillation signals for 5.5 MeV alpha (^{241}Am) and 122 keV gamma (^{57}Co) sources at an anode–cathode potential difference $V_{a-c} = 3.0$ kV are shown in fig. 2a and 2b respectively. The first signal corresponds to a primary scintillation (S1) and the second one to a proportional scintillation (S2). In both figures the time difference of the two peaks corresponds to the electron drifting time from an ionizing point to the anode wires. Due to the slow rise time of the amplifier the signals are integrated. The comparison of the two signals shows that, while the pulse height ratio S1/S2 is considerably bigger than 1 in the case of alpha particles, it is smaller than 1 for gamma rays.

Figs. 3a and 3b show the variations of the scintillation intensity as a function of V_{a-c} for 122 keV gamma ray and 5.5 MeV alpha particles respectively. The Compton scattering effect contribution in the data from the gamma sources is rejected by selecting a signal with two peaks and a narrow gate. The scintillation intensities are normalized to the value of S1 at 0 V for each source. The dependence on V_{a-c} is approximately the same for both sources, except in the case of primary scintillations in a very low electric field, on the contrary a noticeable difference is seen in the ratio S1/S2.

Fig. 4 shows the typical energy spectrum for 122 keV gamma rays from S1 and S2 at $V_{a-c} = 3.5$ kV. Depending on the intensity of the electric field, the energy resolution in the case of S2 is slightly better than for S1 when 4.5 μm anode wires are used. On the

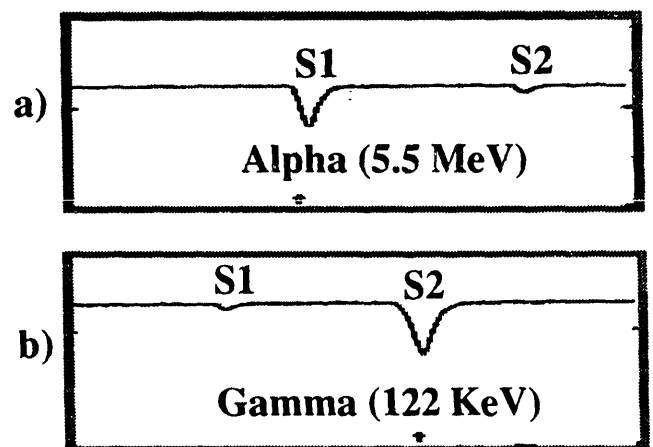


Fig. 2. Scintillation signals for 3 μm wires at $V_{a-c} = 3.0$ kV; (a) 5.5 MeV alpha from ^{241}Am , (b) 122 keV gamma rays from ^{57}Co .

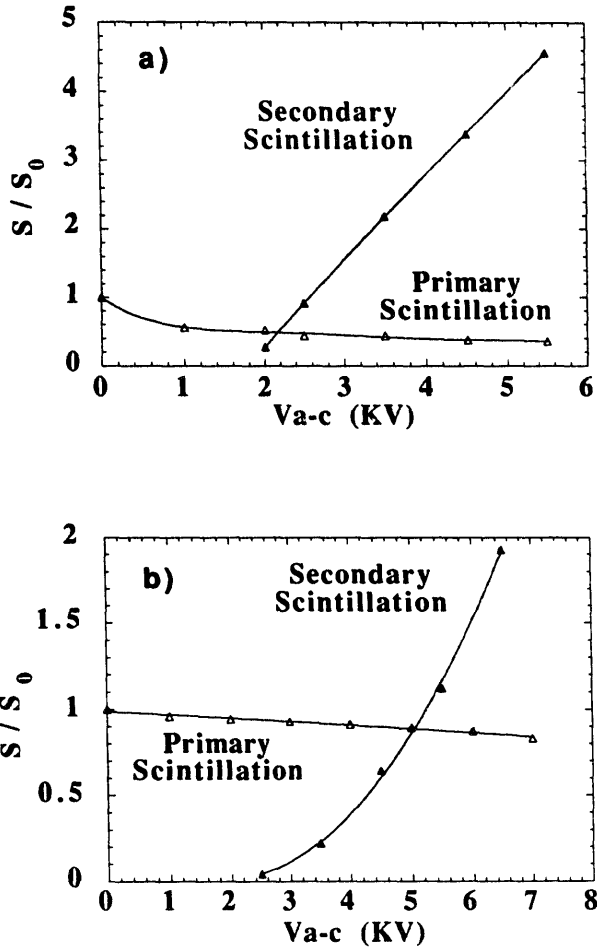


Fig. 3. Variations of the scintillation intensity as a function of V_{a-c} for (a) 122 keV gamma rays and (b) 5.5 MeV alpha particles. The scintillation intensities are normalized to the value of primary scintillation at 0 V for each source.

other hand, if 3 μm anode wires are used, the energy resolution for S2 becomes worse than that for S1. A possible explanation for the poor resolution in the S2

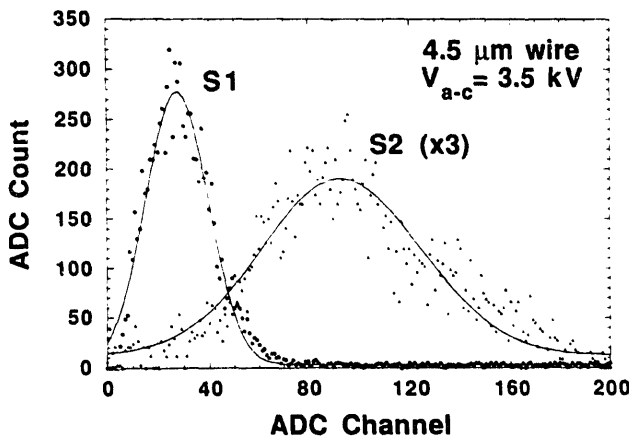


Fig. 4. A typical energy spectrum for 122 keV gamma rays from primary scintillation and secondary scintillation at $V_{a-c} = 3.5 \text{ kV}$ using 4.5 μm wires.

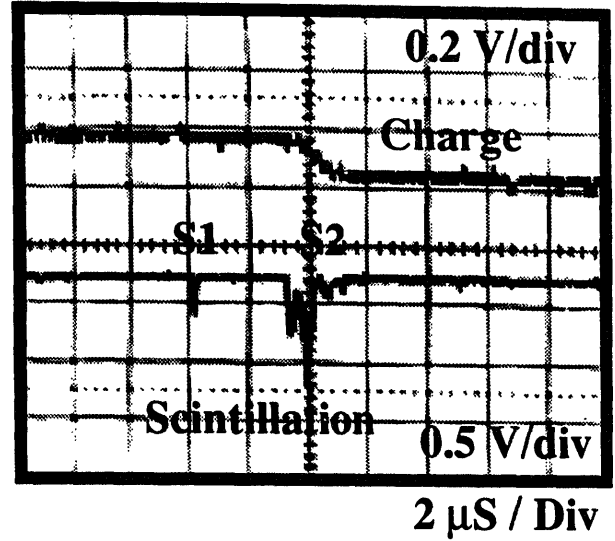


Fig. 5. Charge avalanche signal from preamplifier of 22 keV gamma rays from ^{109}Cd (top) together with the nonintegrated scintillation signal.

case could be a wire nonuniformity and the spread of drifting electrons in the very low electric field between the anode wires. The second problem can be solved by placing an additional grid in front of the anode, as described in section 4. However, the most important requirement for a WIMP detector is not the high energy resolution, but the certainty that there will always exist secondary scintillation to reject gamma ray background. The present test shows that 122 keV gamma rays, whose activity is about 300 cps, produce a single scintillation event in 1% of the cases. The same signature could also be produced by the noise of the photomultiplier or by one of the following processes.

i) Pile-up of S2 on S1 due to ionization in the vicinity of the wire.

ii) Low intensity S1 (or S2).

iii) The absorption of ionization electrons by the wall due to a distortion of the electric field near the wall.

The ambiguity due to process iii) can be resolved by using a special configuration of the chamber and electric field, as described in section 4. The best way to solve the problem of i) and ii) is to require an electron avalanche signal directly on the charge amplifier. The charge avalanche signal of a 22 keV gamma from ^{109}Cd is shown in fig. 5 together with the nonintegrated scintillation signal.

4. Prototype design

The results discussed in section 3 show that in order to reject the cosmic and the radioactive backgrounds, a chamber with 100% charge detection efficiency is

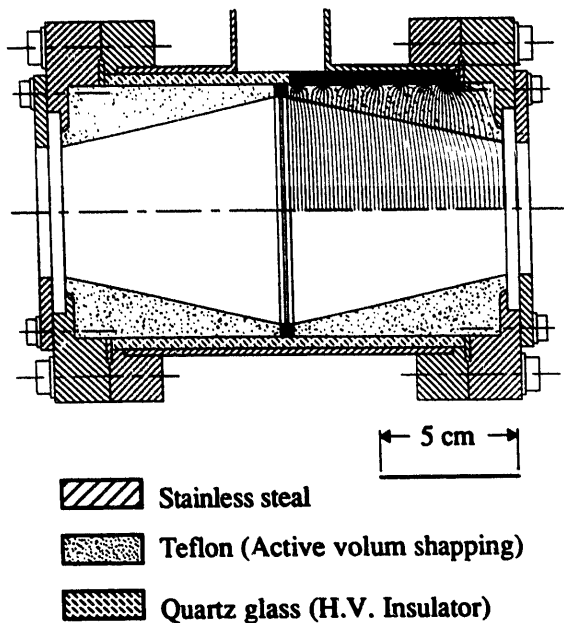


Fig. 6. Cross-sectional drawing of 700 cm³ prototype chamber with the calculated electric field for a quarter part of the chamber. The active volume is surrounded by teflon tube, between the teflon and stainless steel there is a glass tube for insulation between the stainless steel and field shaping rings which is metallized on the inner surface of the glass tube.

needed. To achieve such an efficiency, charge must not be trapped on the wall due to electric field distortions. A chamber with a 700 cm³ active volume has been designed and is at present under construction. Fig. 6 shows a cross-sectional drawing of the chamber. Three wire planes separated by 2.5 mm are located in the chamber center. The central plane is used as the anode and divides the whole chamber into two identical parts, while the remaining two are grid wire planes. In the three planes all the wires are parallel and the pitch is 2 mm. Each plane is staggered by 1 mm with respect to the following. The anode plane consists of 45 wires with a 4 μ m diameter, while the grid has 44 wires with a diameter of 30 μ m. Two groups of six field shaping rings, 6 mm in width, are metallized on the inner surface of the quartz tube. They are spaced by 1 cm and are linked by resistor dividers which are also metallized on the same surface. The electric field (shown in fig. 6), generated by this configuration, causes charge produced by cosmic rays and gammas in the material to drift towards the anode. At each side of the chamber, one UV quartz window (with grounded mesh grid on the inner surface) and one photomultiplier will be mounted for the scintillation readout. The photo-

multiplier noise can be rejected by requiring the coincidence between the signals from the two photomultipliers.

More studies need still to be done: first, we need to investigate the dead regions in the chamber, especially the regions near the edge of each wire plane. A test can be done by depositing a pointlike source on the edge of the grid or the anode wire plane, in order to study the behaviour of events falling in a small region of the volume where the electric field is very weak. The scintillation attenuation and the electron life time tests are planned for this summer. The same purification system as the one used to purify the argon in the ICARUS 2000 l prototype will be used [6]. A neutron beam test is also foreseen, in order to study the low energy heavy ionization response of this type of detector.

5. Conclusions

In this paper we show that our liquid xenon detector can be used effectively to distinguish alpha particles (heavy ionization) from gamma rays (minimum ionization) by using scintillation and charge (proportional scintillation) signals. In comparison, Ge and Si detectors, previously used for direct WIMP detection, are not able to reject background radioactivity noise and electrical noises [7,8]. With NaI detectors it is possible to distinguish gamma rays and heavy ion responses by wave form analysis [9]. However, the method itself is too delicate and the detector's intrinsic radioactivity are relatively high. From such comparisons we believe the LXe proportional scintillation method will be the most reliable way for direct WIMP detection.

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